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Analysis of Mechanical Properties of Coir composites with varied compositions

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Abstract

With the urge to develop materials considering economical, energy efficient and environmental factors, natural fibers composites are increasingly replacing traditional synthetic such as glass fiber composites. In the present study coconut coir dust is used as reinforcement in particulate form with epoxy matrix. The mechanical properties (tensile strength, flexural strength, impact strength) were determined and studied.

Keywords: Natural fiber composite, coir, chemical treatment, mechanical properties, FTIR, SEM

I. INTRODUCTION

Since the 1990s, natural fiber reinforcements such as luffa, bagasse, kenaf, flex, hemp, banana, etc. apparently have been a sensible substitute to various synthetic fiber reinforced composites in many applications. Plant fibers provide a number of techno-ecological advantages over traditional glass fibers such as their renewability, biodegradability, non-toxicity, less abrasive to raw material handling machinery, etc. [1].

Coir is an abundantly and cheaply available lignocellulosic fibre extracted from the dried husk of ripened coconuts (*Cocos nucifera*). It is known to have good wearability and durability but has greater water retention property [2]. Coconut is grown largely in many countries of tropical Asia. Indonesia being its largest producer, the Philippines being second and India being third collectively account for 73% of the world total coconut production. Brazil is the fourth largest producer of coconut in the world. it is known to be used for making wide variety of floor furnishing materials

and mats, yarn, ropes etc. since a very long time. But still a very small percentage of the produced fiber is being utilized. Hence, several research works have been carried out to study the utilization of coir as reinforcement in polymer composites [3]–[12].

Sarocha Charoenvai et al [13] studied varied pre-treatment conditions on coir composites and the SEM micrographs showed enhanced adhesion between fiber and matrix and also in its mechanical properties. Samia S. Mir et al [14] characterized brown single coir fibre for manufacturing polymer composites reinforced with characterized fibres. Adhesion between the fibres and polymer is an important factor affecting strength of manufactured composites. The mechanical properties of double treated (with $CrSO_4$ and $NaHCO_3$) fiber was found to have better properties than single stage treated (with $Cr_2(SO_4)_3 \cdot 12(H_2O)$) fibre which in turn was better than untreated fibre. Bujang et al [15] fabricated composites with randomly oriented discontinuous coir fibers up to 15 vol% and studied its dynamic characteristics. The tensile test conducted showed that the tensile modulus changes with fibre content. The strength tends to decrease with the amount of fibre indicating ineffective stress transfer between the fibre and matrix. The experimental modal analysis showed that the natural frequency decreased with the increase of fiber content while the stiffness factor remains the same. 10% fibre content showed maximum damping peak.

II. MATERIALS REQUIRED

2.1 Coconut Coir

Coir can be used as particulate reinforcement in three different forms: (a) fine coconut dust form (b) Coarse coconut coir with high fiber content (c) Coarse coconut coir with high chip content. In the present study coconut coir was collected locally and was used in fine coir dust form as particulate reinforcement in the fabricated composite. The chemical composition of coir is given in table 1.

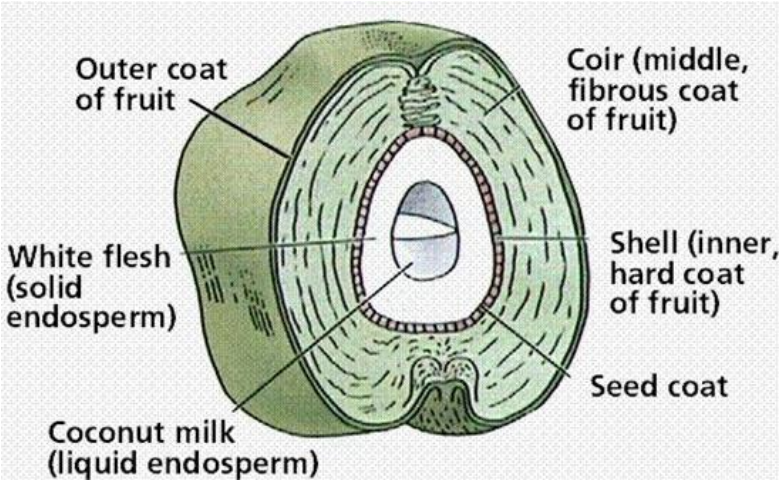


Figure 1: Structure of Coconut

Table 1: Chemical composition of coir [2]

Component	Amount (in %)
Water Soluble	5.25
Pectin and related compounds	3.00
Hemicellulose	0.25
Lignin	45.84
Cellulose	43.44
Ash	2.22

2.2 NaOH

Sodium hydroxide (IUPAC name Sodium oxidanide also known as caustic soda) with molarity 40.00g/mol was used in the present study. Sodium hydroxide pallets were supplied by Emplura®, Merck Life Science Private Limited.

2.3 Epoxy and Hardener

Epoxy (LY556) also known as DGEBA (Diglycidyl ether of bisphenol-A) resin was used. It has (i) Better adhesive properties (ii) Superior mechanical properties (iii) Improved resistance to fatigue and micro cracking, (iv) Reduced degradation from water ingress (v) Increased resistance to osmosis[16]. Hardener (HY951) also known as TETA (triethylene tetraamine) (IUPAC name NN0-bis (2-aminoethylethane-1, 2-diamin)) was used. HY 951 is a low viscosity aliphatic amine. Both epoxy and hardener were supplied by Ciba Geigy India Limited.

III. EXPERIMENTATION

3.1 Chemical Treatment

The collected fibers were first washed thoroughly with normal tap water to remove dirt and other particles adhered to the fiber surface. Then the fibers were mercerized with 5% NaOH solution for 4 hours at room temperature by maintaining liquor to fiber ratio of 15:1. The treated fibers were then washed several times with distilled water to remove any NaOH sticking to the fiber surface until a final pH of 7 was attained. To neutralize the alkali, dilute acetic acid may also be used. The fibers were then dried at room temperature for 48 hours followed by oven drying at 100°C for 6 hours. The mercerization of natural fiber occurs according to equation(1) [17].

$$\mathbf{Fiber - OH + NaOH \rightarrow Fiber - O^{-} - Na^{+} + H_2O} \quad \ldots . \mathbf{Eqn.}\,(\mathbf{1})$$

3.2 Characterization of Fibers

3.2.1 Fourier-transform infrared spectroscopy (FTIR)

The effect of chemical modifications on the fiber surface was studied using FTIR. FTIR measurement was carried out in FTIR Nicolet 6700/ Thermofisher Scientific in

the region 500 – 4000 cm^{-1} and resolution of 0.5 cm^{-1}. KBr pellet technique was used to detect various characteristic functional groups present in the fibers before and after mercerization.

3.2.2 SEM Analysis

The morphology of the fibers before and after treatment with NaOH was examined with 'Zeiss' manufactured Scanning Electron Microscope. To enhance the conductivity of the fibers for their clear viewing a thin film of gold was coated on them using sputter ion coater.

3.3 Preparation of Composite

3.3.1 Mold Preparation

Wooden molds with dimensions 14 mm X 12 mm X 4 mm were prepared and fixed over a cardboard using iron nails. The mold was properly covered with silicon paper.

3.3.2 Composite fabrication

Composites were fabricated using hand lay-up technique. The matrix was prepared by properly mixing Epoxy LY556 and hardener HY951 in a ratio of 10:1 by weight with continuous stirring until the viscosity of the mixture reduces and the entrapped air bubbles get released. The air bubbles from the mixture can further be removed by vacuum. Then the chemically treated fibers with varied weight ratio of fibers wrt. to epoxy matrix (5 wt%, 10 wt%, 15 wt%) were added and well mixed with it. The mold was then sprayed with silicon spray to assist for easy removal of the composite after fabrication. The mixture was then poured onto the mold and covered by silicon paper followed by glass plate. A weight of 5kg was put over the glass plate for removal of trapped air inside the mixture. Curing of epoxy matrix compose occurs at room temperature over a period of 24-48 hours. After 48 hours the mold was broken and the fabricated composites were ejected out.

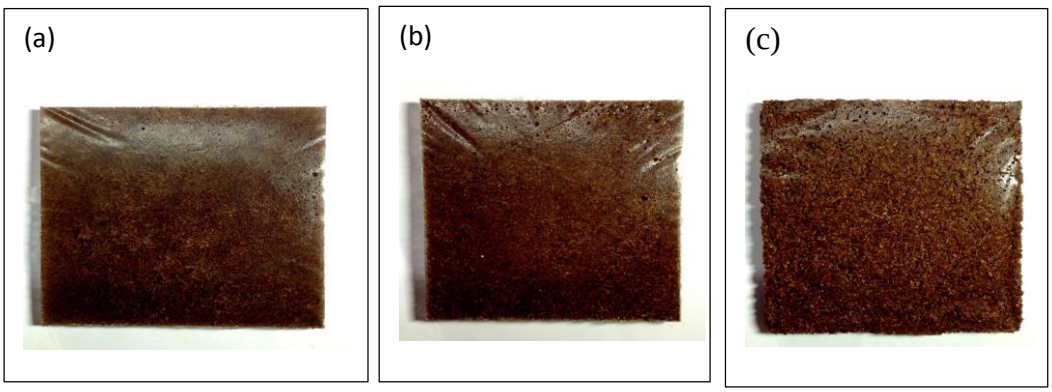


Figure 2: (a) Coir 5wt%; (b) Coir 10wt%; (c) Coir 15wt% composite

3.4 Testing of Mechanical Properties

3.4.1 Tensile Test

Tensile test specimens were cut in dog-bone shape of dimensions (140mmX15mmX10mm) with a gauge length of 5mm as per ASTM standard. Tensile strength of the prepared samples was tested using the 3382 Floor Model Universal Testing Machine, INSRON (10 ton) with a strain rate of 1mm/min. Young's modulus or the elastic modulus was obtained as a measure of the stiffness of the composite.

3.4.2 Flexural Strength

Flexural test specimens were cut in the shape of rectangular bar of dimensions (120mmX10mmX10mm) as per ASTM standard. Flexural strength of the samples prepared was tested using the 3382 Floor Model Universal Testing Machine, INSRON (10 ton) with a strain rate of 2mm/min over a span length of 70mm. Flexural modulus or bending modulus was computed as a measure of tendency of the material to bend.

3.4.3 Impact Strength

Impact test specimens were cut as per ASTM standard Charpy impact test in dimensions of (7.5mmX10mmX10mm) with a notch of 2mm cut at the center of specimen at 60^0. The impact tester with an accuracy of ±0.022J was used as per ASTM standard D256.

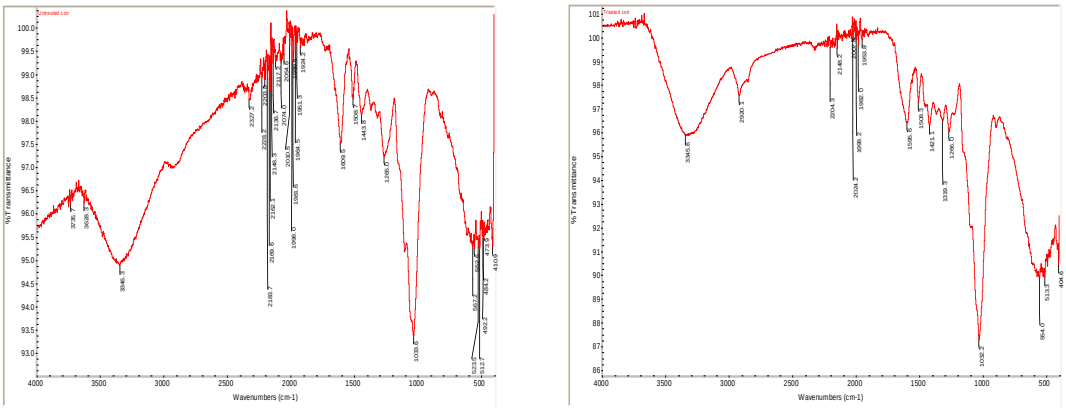
IV. RESULTS AND DISCUSSION

Natural fibers are made of cellulose, hemicellulose and lignin. Preparation of polymer–cellulose composites are hindered by the highly hydrophilic nature of these fibers while the polymers used for matrix preparation are usually hydrophobic creating compatibility issues resulting in loss of mechanical properties after moisture uptake [18]–[20]. Due to the poor compatibility, surface of fibers must be modified so as to make it less hydrophilic and improve the interface interaction between the fiber and the matrix.

Syed H. Imam et al [21] studied the effect of different treatments (washing with water, treatment with alkali also known as mercerization and bleaching) on tensile and thermal properties of coir composites with starch/ethylene vinyl alcohol copolymers (EVOH). SEM characterization of fiber surface morphology showed that mercerization produced the most desirable result with increased gluing between fiber and matrix and 53% increase in tensile strength compared to composites with raw fibres. It also further ameliorates fiber–matrix adhesion for better stress distribution between matrix and the fibres.

4.1 Fourier-transform infrared spectroscopy (FTIR)

Amount of lignin in coir dust is relatively high. Coir dust has a typical lignocellulosic composition, presenting bonds at 3354 cm^{-1} assigned to O-H stretch, at 2938 cm-1 assigned to C-H stretch from methyl and methylene groups [22].The peak at 1625cm^{-1} represents the C=O bonds on hemicellulose from carboxylate groups and at 1462 cm^{-1} assigned to CH_2 symmetric bending peaks. The peaks at 2922 cm^{-1} represents the C-H stretching in methyl group, and at 3430-3450 cm^{-1} represents O-H stretching in free alcohol. The removal of lignin and hemicellulose from the coir dust surface causes peaks at 3354 cm^{-1} and 2938 cm^{-1} to disappear [23][24].



(a) **(b)**

Figure 3: FTIR spectra of (a) Untreated Coir fiber; (b) Alkali treated Coir fiber

4.2 SEM Analysis

The SEM micrographs of untreated fiber and treated fiber could be seen in figure 9(a) and (b) respectively. Chanakan Asasutjarit et al. [25] studied the effects of pre-treatment of coir. Composites were prepared using coir fiber treated with varying pre-treatment conditions. Surface characterizations of the untreated and pre-treated coir fiber were investigated using scanning electron microscopy (SEM) which revealed that there is an improved adhesion between fiber and matrix in case of pre-treated coir.

The presence of an amorphous waxy cuticle layer seen on fiber surface contributes to poor fiber–matrix adhesion [26]. Scanning electron micrographs of raw coir fibre showed rougher surface while that of the treated coir fibre was found to be clean and smooth [14].This is due to removal of gummy and waxy substances- lignin and hemicellulose from the fiber surface.

It can be observed that the alkali treatment resulted in separation of the micro fibrillar structure (fibrillation) and reduction in thickness of fiber due to removal of cemented materials like lignin and hemicellulose [27][28]. The fibrillation increases effective surface area available for contact with the matrix [29] and thus improves the

interfacial adhesion between the fiber and the matrix. The SEM results revealed removal of lignin, pectin and hemicellulose substances, and change the characteristics of the surface topography.

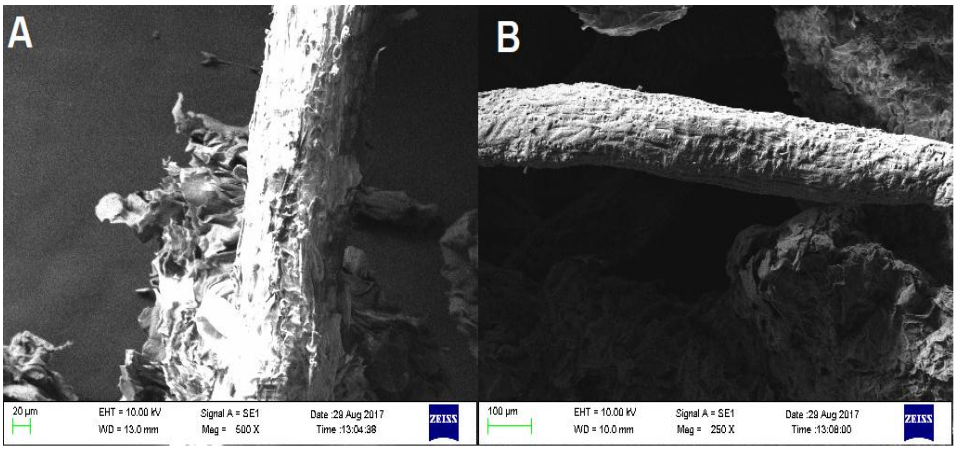


Figure 9: Micrograph of coir fiber(A) Untreated Coir; (B) Treated Coir

4.3 Mechanical Strength

The mechanical properties of composites with coir reinforcements has previously been studied by several researchers. A. Bensely et al [30] developed coir composites and studied their mechanical properties. Scanning electron micrographs of fractured surfaces were used for qualitative evaluation of the interfacial properties of coir/epoxy and were compared with glass/epoxy composites. These results establish that coir can be used as a potential reinforcing material for low load bearing thermoplastic composites. A.zuradia et al [31] studied the effect of fibre length on mechanical properties of coir fibber reinforced cement-album composites. It was concluded that increasing the fibre length increases the flexural strength but incorporation of long fibre into the cement reduced its workability as voids were introduced which resulted in low density, increase in water absorption and water content. Rahul A.khan et al [32] studied the mechanical properties of coir fiber ethylene glycol dimethacrylate base composites. The surface of the coir fibres was modified with monomer EGDMA under UV radiation. Pre-treatment with UV radiation on the coir fiber effectively improved its mechanical properties. The surface of the fiber was also mercerized (alkali treatment) using aqueous NaOH solutions (5–50%) at varied time and temperature. It was found that TS of the mercerized composites increased with the increase in NaOH solutions (up to 10%) and then decreased. The composites made using mercerized fibres treated with ethylene glycol dimethacrylate (EGDMA) showed further increase in TS. Pre-treatment with mercerization + UV treatment of coir fiber showed significant improvement in the mechanical properties of the coir fiber-based composites.

4.3.1 Tensile Strength

Maximum tensile strength obtained by coir dust reinforced epoxy polymer composite decreases after 10wt% increase in percentage of coir addition. This is because with lower percentage of coir there is better wetting of its particles by the epoxy matrix.

The maximum tensile strength obtained by the composites and Young's modulus of the composites is depicted by the graphs shown in figure 4 and 5 respectively.

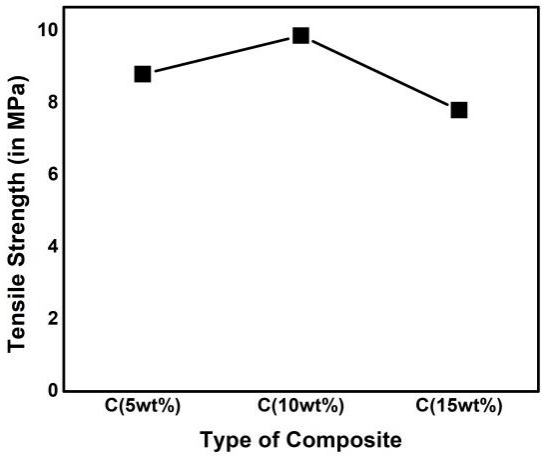


Figure 4: Tensile Strength of Coir composites

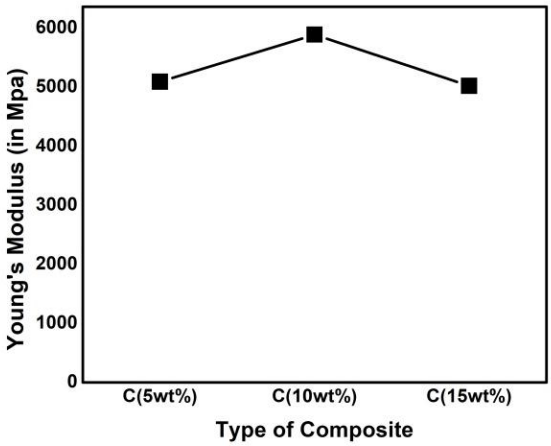


Figure 5: Young's Modulus of Coir composites

4.3.2 Flexural Strength

Maximum flexural strength obtained by coir dust reinforced epoxy polymer composite decreases with increase in percentage of coir addition after a certain

amount. This could again be due to better wetting of coir particles by the epoxy matrix for lower percentage of coir. The maximum flexural strength obtained by different composites is depicted by the graphs shown in figure 6. Flexural modulus of the fabricated composites is plotted in figure 7.

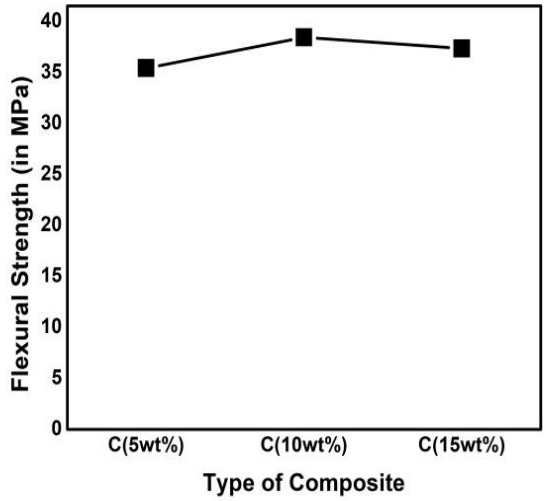


Figure 6: Flexural Strength of Coir composites

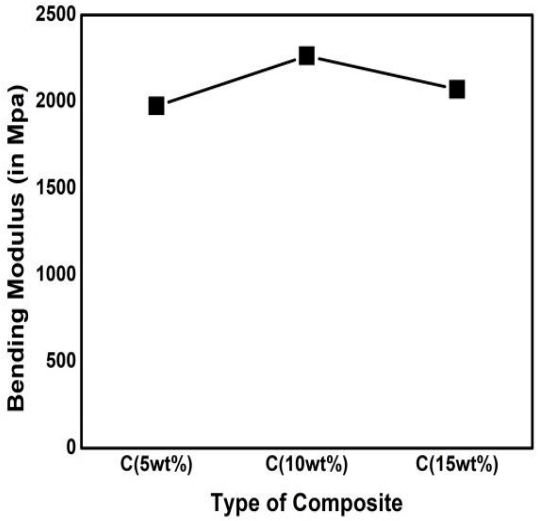


Figure 7: Bending Modulus of Coir composites

4.3.3 Impact Strength

Maximum impact strength obtained by coir dust reinforced epoxy polymer composite increases with increase in percentage of coir addition. This is because of higher

compactness of composites achieved for higher percentages of coir addition in the composite. This is depicted in graph plotted for figure 8.

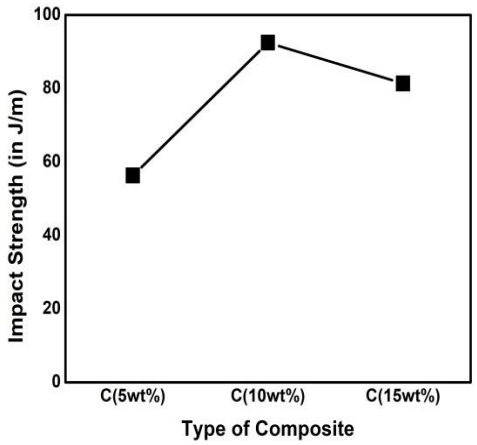


Figure 8: Impact Strength of Coir composites

V. CONCLUSION

Composites with mercerized coir reinforcements in epoxy matrix were prepared by hand lay-up technique and their mechanical properties like tensile strength, flexural strength and impact strength were determined. The effect of mercerization on the fibers was also analyzed by FTIR and SEM analysis of the treated and untreated fibers.

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